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RADIATION IN THE UNIVERSE AND COSMIC ELECTRONS

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ABSTRACT. The paper discusses the problem of sources of background radiations which may be the integral radiations of the Metagalaxy.

Two hypotheses are analyzed. The first is the dual hypothesis, based on the assumption that the soft (radio) portion of background radiation is formed in synchrotron breaking, while X-radiation is formed in the course of the reverse Comptom effect. The second, or synchrotron hypothesis, assumes that all background radiation was formed by the breaking of electrons in the magnetic field.

Within the framework of these hypotheses, the conclusion is reached that the principal contribution to the background radiation is made by large ($\gtrsim$ two) Z, while in the dual hypothesis the principal role is played by conventional galaxies, while within the framework of the synchrotron hypothesis the effects are produced by powerful radio galaxies and quasars. The ionization of the intergalactic gas by ultraviolet radiation is analyzed; within the framework of both hypotheses, this gas must exist in the Metagalaxy.

The difficulties of both hypotheses and ways of testing them are analyzed.

Introduction

The expansion of the Universe has for a long time been the only experimental confirmation of explosive cosmological models. /3*

A similar situation is encountered on the experimental plane, apparently due to the fact that observations of extragalactic objects are made in the optical range, where there are significant background radiations, and receivers do not have adequate sensitivity. However, there are other more basic aspects to the problem [1, 2]. Theoretical relationships (the observed density of galaxies from the red shift Z, the dependence of stellar magnitude of galaxies upon Z and the dependence of their angular dimensions on Z) require observations at distances of $Z \gtrsim 1$ (so that the corrections that are necessitated by the curvature of space increase as the square of Z), while the principal results of

*Numbers in the margin indicate pagination in the foreign text.

observations in the optical range have been obtained at $Z \lesssim 0.2$, so that Newtonian mechanics are well described in Euclidian space.

On the other hand, the theoretical calculations are based on the assumption of standardization and unchangeability of galaxies. In reality, galaxies /4 are characterized by a wide spectrum of sizes, and their properties can change with time (evolution of sources).

In such a case, theoretical relationships cannot be compared with experiment and consequently cannot be combined to establish the nature of the Universe.

It is considered probable, that the achievements of radio and extra-atmospheric astronomy will have definite advantages in overcoming these difficulties.

A familiar reason for such optimism is the discovery of relict radiation, which apparently is of cosmological origin[1]. In this case the evolutionary models make it possible to calculate its parameters all the way to very short times, elapsing from the beginning of expansion.

Another important factor is the investigation over the wide range of energies of the isotropic radiations which naturally are identified with the integral radiations of the Universe. Both of these experimental facts allow us to proceed to an independent determination of the evolution of radiation sources and to establish the dynamics of processes which occur in non-stationary objects.

We shall use two methods to solve these problems.

The first of them leads to an investigation of the interactions of cosmic rays with the relict radiation and possibly with the light field of the Metagalaxy. /5

The principle idea is based on the fact that in the course of interaction of cosmic rays with radiation (formation of vapor, reverse photoeffect and pion

[1]However, in view of the fundamental importance of this finding, it is necessary to establish its proof on a more firm basis, in particular, to clarify the nature of the infrared background [3], and to understand the behavior of cosmic rays in the energy range greater than 10^{19} eV (see below).

production) there is a change in the nature of their energy spectrum which may be observed in experiments. A comparison of the calculated[2] and experimental data makes it possible to draw the following conclusions (for more detail see example [4] and [4a]: I) interaction with light may play a role only in the not very probable assumption of a very considerable evolution of light sources. In this case, the break in the energy spectrum of cosmic rays in the region $E_n \sim 10^{15}$-10^{16} eV is explained by their interaction with light; (2) if the evolution of light sources is small, this gap is explained by the different origin of cosmic particles of small (less than 10^{15} eV - galaxy) and large (more than 10^{16} eV - Metagalaxy) energies.

It is most important, however, to explain the absence of a sharp bend in the energy spectrum at $E \sim 10^{19}$ eV, predicted on the basis of calculations of the results of interaction of cosmic rays with relict radiation [5]. In order to make the results of calculation and experiment agree, without making /6 any new cardinal hypothesis it is necessary to assume either that the cosmic rays consist of heavy nuclei or that they arise comparatively close to our galaxy[3].

I. Background Radiation. Statement of the Problem

The figure shows the experimental data on isotropic background radiation. This problem has been studied repeatedly in recent years. To construct the relationships, we have used the summary data presented in [6-11][4]. Our figure does not contain data on soft X-rays ($E_\gamma \sim 240$-280 eV), obtained recently [12-14]. In our opinion (for more details see [15]), the high intensity of the radiation in this region is explained either by the interaction of electrons in the upper layers of the atmospheres or by methodical effects. The relationship shown in the figure has the following peculiarity. The region of radio

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[2]Here and later on, we have in mind the calculations based on the Friedman model ($\lambda = 0$; $\rho/\rho_c = 1$; $\rho_c \sim 10^{-29}$ g·cm^{-3} is the critical density).

[3]Still greater difficulties arise with the assumption that the observed infrared radiation [3] filled the entire Metagalaxy.

[4]Note that the accuracy and reproducibility of the experimental data on background radiation require improvement.

background ($V \sim 10^7$-10^{10} Hz) and X-ray background ($V \sim 10^{17}$-10^{19} Hz) is the only step rule with an exponent $\gamma_\gamma = 1.7$-1.8. In the region $V \sim 10^{19}$ Hz /7
($E_\gamma \sim 40$-60 keV) the spectrum contains a gap and is approximated by a step function with a exponent $\gamma_\gamma = 2.2$ all the way to $V \sim 10^{22}$ Hz ($E_\gamma \sim 100$ MeV).

This peculiarity of the energy spectrum of the background radiation provides a basis for two hypotheses regarding its origin.

The first hypothesis (for the sake of brevity, we shall refer to it as the dual hypothesis) consists in the assumption that the radio background arises in the process of synchronous radiation, while the X-ray and photon backgrounds are due to the reverse Compton effect of the cosmic electrons on the relict radiation.

The second hypothesis is the synchrotron hypothesis. The entire spectrum of background radiation is due to a magnetic braking mechanism. The purpose of this paper is to analyze the assumptions and the conclusions of both hypotheses.

II. Principle Conclusions of the Dual Hypotheses

A detailed analysis of the dual hypotheses was conducted in [15]. For the sake of completeness, we shall present the basic conclusions of this paper here.

The principle assumption that was relative to the conditions of propagation of electrons led to the conclusion that if the energy spectrum of the electrons at the sources has a stepped form, the spectrum of the photons will have a stepped form.

Therefore, it follows from the fact that the spectrum of X-ray radiation /8
has a gap at $E_\gamma \sim 40$-60 keV that within the framework of the hypothesis under discussion we can conclude that the electron spectrum at the sources has a discontinuity in it.

The intensity of X-rays observed in experiments is explained on the basis of an assumption regarding the powerful evolution of electron sources. Therefore, the effect of distances at which X-radiation is formed correspond to $Z \gtrsim 2$-3. At these distances, the density of the relict radiation is great

(approximately 100 greater than at the present time) so that the electrons lose the principle portion of their energy within the limits of the galaxies. The principle sources of X-radiation and radio background are normal galaxies in which the magnetic field is not changed from the moment of their formation.

III. Metagalactic Ultraviolet Radiation

If this hypothesis is correct, there must be significant ultraviolet radiation in the Metagalaxy. This conclusion is not completely trivial for the reason that a simple extrapolation of the energy spectrum of X-radiation /9 in the ultraviolet region is required in the basis due to processes that agree with reverse Compton effect, and a possible discontinuity in the spectrum of cosmic electrons as far as low energies are concerned. This section is devoted to an analysis of these problems.

The X-radiation with $E_\gamma \gtrsim 1$ keV in the course of the reverse Compton effect is produced with electrons with $E_e \gtrsim 1$ GeV. The alternative is also possible:

1) The spectrum of the electrons at the sources extends into the region of low energies (less than about 100 MeV) when ultraviolet quanta arise in the course of the reverse Compton effect, and,

2) The spectrum of electron generation breaks at $E_e \gg 100$ MeV, but following braking by relict radiation, it will shift to the region of lower energies, where it is unavoidable to have formation of ultraviolet radiation.

Let us consider the problem of the concurrent processes that lead to energy losses of electrons with $E_e < 1$ GeV. The braking radiation and ionization losses do not play any role up to $E_e \sim 100$ MeV, if the average density ρ of the substance in the Universe does not exceed the critical value significantly ($\rho \lesssim \rho_c$)

Let us spend some time in discussing in detail the influence of the red shift, assuming that the differential relationship between the path X and the red shift Z is determined by the Friedman model with Euclidian metrics[5]:

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[5]The possible change in curvature in space has no influence on the following conclusions.

$$dx = \frac{c}{H_0}\,\omega^{-1/2}\,d\omega, \qquad (1)$$ /10

Where H_0 is the Hubble constant in our era; $w = 1/1 + Z$. The equation described in the origin in the Metagalaxy of electrons with an energy $E_e \gtrsim$ $\gtrsim$ 100 MeV has the form:

$$-\frac{dE_e}{d\omega} = \frac{E_e}{\omega} + \frac{E_e^2}{E_{ek}}\,\omega^{-3.5}, \qquad (2)$$

Where $E_{ek} = 3H_0(mc^2)^2/4c\sigma_T W_{20}$ is the energy at which the energy losses balance the red shift and the reverse Compton effect in our era ($\sigma_T \approx 7\cdot 10^{-25}$ cm^2 is the Thompson cross section; $W_{20} \approx 0.25$ eV cm^{-3} is the density of the energy of relict radiation in our era.

Equation (2) has the following solution:

$$E_e(\omega) = \frac{E_{e0}}{\omega}\,\frac{1}{1 - \frac{E_{e0}}{E_{ek}}\,\frac{\omega^{-3.5} - 1}{3.5}}, \qquad (3)$$

Where E_{e0} is the electron energy at $w = 1$. It follows from equation (2) that if $E_e > E_k$, then even in our era the losses to the reverse Compton effect will prevail over the losses caused by the red shift. Therefore, in the reverse Compton effect, involving relict radiation $E_\gamma \sim 4/3\ E_{20}(E_e/mc^2)^2$ (E_{20} is the energy of the quanta of relict radiation in our era), this means that we can /11 disregard the losses due to the red shift all the way to energies of $E_\gamma \gtrsim$ $\gtrsim$ 30-40 eV. We will be interested in photons all the way to energies of about 10 eV (corresponding to $E_e \sim 100$ MeV). In this case, even at $Z > 0.3$ we can disregard the red shift. Therefore, we shall perform our calculations in the future with this omission taken into account[6].

At any point in the Metagalaxy at which the energy of the relict quanta E_R, an electron with an energy E_{20} will form photons with the spectrum:

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[6]Several estimates of the influence of the red shift on the radiation of soft ultraviolet are given in appendix 1.

$$n(E_\infty, E_\gamma) = \frac{1}{2}\left(\frac{mc^2}{E_R}\right)^{1/2} E_\gamma^{-3/2}\,\theta\left(\frac{4}{3}E_R\left(\frac{E_\infty}{mc^2}\right)^2 - E_\gamma\right) \qquad (4)$$

Where θ is the step function. Using the standard expressions for the Friedman model, we can obtain the expression $F(E_\gamma)$ for the energy spectrum of photons at any point in space:

$$F(E_\gamma) = \int_{\omega_i}^{1} d\omega\, \omega^{1/2} \int_{\alpha}^{\infty} n(E_e, E_\gamma \omega^{-1}) P(E_e)\, dE_e, \qquad (5)$$

Where $\alpha = mc^2\sqrt{3E_\gamma/4E_2}$; $P(E_e)$ is the energy spectrum of the electrons at the sources.

Following the integration we will have: /12

$$F(E_\gamma) = \left(\frac{mc^2}{E_{R0}}\right)^{1/2} \frac{1-\omega_i^{4.5}}{4.5} E_\gamma^{-1.5} \int_{\alpha}^{\infty} P(E_e)\, dE_e \qquad (6)$$

Where $w_i \ll 1$ corresponds to the rise time for the electron sources.

Note that (5) and (6) due not consider absorption of the ultraviolet by the intergalactic gas and the evolution of electron sources. As will be shown in the following section, the rising ultraviolet rapidly ionizes the intergalactic gas, and we can therefore disregard its absorption.

The influence of evolution is apparent in a region where the red shift is significant. Therefore, the possible evolution may only lead to a slight increase in the intensity of the soft ultraviolet. For further calculations, we will approximate the spectrum of the electrons of the step function, cut-off on the low energy side at a certain value E_{eL}:

$$P(E_e) \sim E_e^{-\gamma_e}\,\theta(E_e - E_{eL}). \qquad (7)$$

Then the total energy E_{12} of the photons with energies located in the range $E_{\gamma 1}$ and $E_{\gamma 2}$ ($E_{\gamma 1} < E_{\gamma 2}$) is determined by the expression /13

$$\varepsilon_{12} \sim \frac{1}{2-\gamma_e}\left[E_{\gamma 2}^{-\frac{\gamma_e-2}{2}} - E_{\gamma 1}^{-\frac{\gamma_e-2}{2}}\right], \qquad (8a)$$

$$E_{\gamma 1} > E_{\gamma L} = \frac{4}{3} E_{RO}\left(\frac{E_{eL}}{mc^2}\right)^2;$$

$$\varepsilon_{12} \sim 2E_{\gamma L}^{-\frac{\gamma_e+1}{2}}\left[E_{\gamma 2}^{1/2} - E_{\gamma 1}^{1/2}\right], \qquad (8b)$$

$$E_{\gamma 2} < E_{\gamma L}.$$

In the following, we shall be interested in the ratio of the total energies $E_{12}^{(1)}$ and $E_{12}^{(2)}$, located in two non-intersecting ranges ($E_{\gamma 1}^{(1)}$, $E_{\gamma 2}^{(1)}$, $E_{\gamma 1}^{(2)}$, $E_{\gamma 2}^{(2)}$). It is easy to see that the ratio in which we are interested is determined by formulas (8a) and (8b) as a function of the inequality:

$$\begin{aligned} &1.\ E_{\gamma 1}^{(1)} > E_{\gamma L} \quad E_{\gamma 1}^{(2)} > E_{\gamma L}, \\ &2.\ E_{\gamma 2}^{(1)} < E_{\gamma L} \quad E_{\gamma 1}^{(2)} > E_{\gamma L}, \\ &3.\ E_{\gamma 2}^{(1)} < E_{\gamma L} \quad E_{\gamma 2}^{(2)} < E_{\gamma L}. \end{aligned} \qquad (9)$$

Now let us evaluate the ratio $E_{12}^{(2)}/E_{12}^{(1)}$, where $E_{12}^{(1)}$ corresponds to the well-known range of radiation in the X region from 1-10 keV. Then ratios (8) and (9) make it possible to calculate the energy $E_{12}^{(2)}$ of the radiation in the ultraviolet region (we will consider it to be equal to 10-100 eV). /14

It is obvious that the ratio $E_{12}^{(2)}/E_{12}^{(1)}$ depends on the value of $E_{\gamma L}$ and consequently on E_{eL} as well as the value γe.

The upper limit of the values of E_{eL} may be estimated from the following relationships. We know that the spectral index of the non-thermal radio back-

ground, as well as the radio radiation of galaxies all the way to frequencies $\gtrsim 5$ Mhz, does not undergo a significant change. At frequencies $\lesssim 5$ Mhz, there is a drop in the spectra, usually interpreted as the result of absorption of long-wave radiation. If the principle contribution to radio background is made to the radio galaxies, the effective voltage of the magnetic field $H \sim 10^{-4}$ Oe, if the galaxies are similar to ours, then $H \gtrsim 3 \cdot 10^{-6}$ Oe. For estimating the upper limit of E_{eL} we will use the latter value, which gives a known upper limit E_{eL}. In this case $E_{eL} \sim 5 \cdot 10^8$ eV (a). Another method of estimating E_{eL} is to generalize the energy spectrum of electrons measured at the limit of the atmosphere for all sources. In such an extrapolation, which gives the lower limit, $E_{eL} \ll 100$ MeV (b).

It is possible to estimate γ_e on the basis of the spectrum of X-radiation. /15 If we assume (see [15] and Section I) that the electron spectrum in the sources undergoes a discontinuity in the region $\lesssim$ 3-5 GeV, then with $E_e \lesssim$ 3-5 GeV $\gamma_e' \approx 2.5$ ($\gamma_e' = \gamma_e + 1$).

In accordance with the latter measurements [16], $E_{12}^{(1)} \sim 3 \cdot 10^{-5}$ eV cm^{-3}. Using this value in formulas (8) and (9), we can obtain the value $E_{12}^{(2)}$ for the ultraviolet range for different values of E_{eL} and γ_e' (Table 1).

TABLE 1

E_{eL}(eV)	$5 \cdot 10^8$		10^8	
$\gamma_{e'}$	2.5	3.7	2.5	3.7
$E_{12}^{(2)}$ (eV cm^{-3})	$3 \cdot 10^{-6}$	$5 \cdot 10^{-6}$	$4 \cdot 10^{-6}$	$1.5 \cdot 10^{-4}$

In the columns corresponding to the index 3.7, values of $E_{12}^{(2)}$ are used which were obtained on the assumption that the spectrum of the electrons is described by a function with a single subscript for a wide range of energies [11].

The values of $E_{12}^{(2)}$ which are obtained lead to large fluxes of ultraviolet quanta. Since with $\gamma_e' \approx 2.5$ (the most natural assumption) the flux is $\sim 5 \cdot 10^3$ kV cm^{-2} sec^{-1}; with $\gamma_e' \approx 3.7$ the flux is 10^5 kV cm^{-2} sec^{-1}. /16

At the present time, we have very limited data in regard to the upper limit of the ultraviolet background (Court [17]); the measured value exceeds both of the values given above. Therefore, it is extremely desirable to make the experimental data more exact.

However, there are some interesting questions we could pose at this point.

Syunyayev [18] noted that the value of the ultraviolet background, exceeding 10^4 kV cm^{-2} sec^{-1}, contradicts the observed distribution of neutral hydrogen at the periphery of the galaxies. This finding is in contradiction to the model which has been developed in parallel [11].

The appendix 1 is shown that even a low probability assumption regarding the cut-off of this spectrum of electrons and the sources does not reduce this contradiction. This additional indication that the observed high intensity of soft X-radiation background ($E_\gamma \sim 240$-280 eV) cannot be explained by the reverse Compton effect.

IV. Ionization and Heating of Intergalactic Gas /17

The kinetics of the heating of the intergalactic gas was investigated first by Ginzburg and Ozern [19]. The approach to this problem was based on the assumption that the sources of heat were subcosmic rays and essentially non-stationary objects (radio galaxies, quasars, etc.). Consequently, this approach was developed repeatedly (see for example [20, 21]). The estimates made in these works showed that these sources indicated were insufficient not only for heating to the high temperature $T \sim (10^5$-$10^6)$°K, but also the maintain it for a long time, if the density of the substance in the Universe in order of magnitude is equal to or greater than the critical density.

Attempts have been made to approach the problem of heating of intergalactic gas "experimentally." Thus, the sometimes observed isotropic X-radiation was interpreted as a possible occurrence of radiation of heated Metagalactic gas

as $\rho \sim \rho_c$ (see for example [22, 23]). However, the stepped spectrum of the isotropic X-radiation contradicts this assumption. Hence, such an approach may give only the upper limit of the values T.

Another approach has to do with the interpretation of the results of Hanna and Peterson [24], who found that in the vicinity of quasar ES-9, the distance to which is approximately $Z \approx 2$, the density of the neutral hydrogen is low ($n_H < 6 \cdot 10^{-11}$ gsm^{-3})[7]. On the basis of these results, and assuming that the density of the Metagalactic gas is great ($\rho \gtrsim \rho_c$), they concluded that T was large in value. However, this system does not agree [21] with the results of Koehler's experiments [27] in regard to the high density of the neutral hydrogen ($> 4.4 \cdot 10^{-7}$ parts per cm^{-3}) in the immediate vicinity ($Z \sim$ ~ 0.1). Hence, the situation involving the heating and ionization of intergalactic gas is now rather indeterminate. /18

It seems to us that a factor which might clear up the situation to some extent is the intergalactic ultraviolet radiation of significant intensity.

As we showed in the preceeding section, if we accept the assumption that the isotropic X-radiation (with energies $\gtrsim 1$ keV) is weakened by the reverse Compton effect with the relict radiation, there must be intense radiation in the ultraviolet region in the Metagalaxy[8].

Let the energy spectrum of the electrons in the sources be expressed by the generalized function (7): /19

$$P(E_e) = AE_e^{-\gamma_e} \omega^{-(3+\beta)} \theta(\omega - \omega_i), \qquad (10)$$

where A, γ_e, β and w_i are constants.

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[7]It is possible that the data [24] would give a somewhat lower value n_H. See the discussion in [25, 26].

[8]All of the following remained valid even with the alternative assumption that the Metagalactic radiation in the radio, ultraviolet and X-ray regions is caused by a single magnetic-braking mechanism, and the ultraviolet escapes significant absorption from sources in the Metagalaxy, see the next section.

The constants A, γ_e and β are determined on the basis of the intensity and the spectrum of the X-radiation [5]. Then the differential flux of ultraviolet radiation in the region $E_\gamma \gtrsim 20$ eV corresponds to the expression[9]:

$$F(E_\gamma) \sim 10\omega^{-3}\,\frac{\omega^{-\beta+2.5} - \omega_i^{-\beta+2.5}}{1 - \omega_i^{-\beta+2.5}}. \qquad (11)$$

where $E_\gamma^{-1.6}\,\theta(w - w_i)$ $(cm^{-2}sec^{-1}keV^{-1}ster^{-1})$.

Let us examine the stationary ionization

$$\frac{dn_H}{dt} = \frac{dn}{dt}, \qquad (12)$$

where n_H and n are the concentrations of the neutral and ionized atoms, respectively.

The rate of ionization /20

$$\frac{dn_H}{dt} = 4\pi n_H \int_{E_i}^{\infty} F(E_\gamma)\,\sigma(E_\gamma)\,dE_\gamma. \qquad (13)$$

The photoionization cross section:

$$\sigma \approx 6\cdot10^{-18}\left(\frac{E_i}{E_\gamma}\right)^3 cm^2 \qquad (14)$$

where E_i = 13.6 eV.

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[9]Formula (11) was obtained for $\rho/\rho_c = 1$. The final expressions are dependent very little on the value of this parameter.

The degree of ionization n_H/n depends on the coefficient of recombination α, i.e., on the temperature of the intergalactic gas. No reliable estimates on the value of T of any kind are available[10]. Therefore we shall estimate the value of α for two temperature values: $T_1 = (10^5)°K$ and $T_2 = (10^3)°K$. In the first case, $\alpha_1 \sim 10^{-13}$ cm^3 sec^{-1}; in the second, $\alpha_2 \sim 5 \cdot 10^{-13}$cm^{3}sec^{-1}. In the general form, with $n_H/n \ll 1$):

$$\frac{n_H}{n} = \frac{\alpha n (w=1)}{4\pi \int_{E_i}^{\infty} F(E_\gamma)\sigma(E_\gamma)dE_\gamma} \cdot \frac{1 - w_i^{-\beta+2.5}}{w^{-\beta+2.5} - w_i^{-\beta+2.5}} . \qquad (15)$$

formula (15) is simplified for two important partial cases: $\beta \ll 2.5$ (weak evolution) and $\beta \gg 2.5$ (strong evolution). Assuming that $w_i \ll 1$ and $w/w_i \gg$ $\gg 1$, it is easy to see that in the case of weak evolution, by way of approxi- /21
mation, we will have $n_H/n \sim w^{-2.5}$; with strong evolution, the ratio n_H/n will be constant.

It follows from equations (11) to (15), for example, that with $T = T_1$

$$\frac{n_H}{n}(w=1) = 2 \cdot 10^{-4} \frac{\rho}{\rho_c} .$$

If we relate the results of Hanna-Peterson to the entire Metagalaxy[11], we can then obtain an estimate of the density of the intergalactic gas. With $T \sim T_1$, $\rho \lesssim 0.2$, ρ_c (strong evolution) and $\rho \lesssim 5 \cdot 10^{-2}$ ρ_c (weak evolution). With $T = T_2$, the values are approximately two factors less.

V. Synchronous Hypothesis of the Origin of Background Radiation

If we interpolate the energy relationships of the radio and X-radiation with energies of 1-20 keV, the interpolated curve will be a straight line in the logarithmic scale with a high degree of accuracy (see the dotted curve in Figure 1); this curve will be an extension of both parts (radio and X-radiation).

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[10]Several estimates of the kinetics of the heating of intergalactic gas by ultraviolet are given in appendix 2.

[11]Similar interpretation is not necessary (see [26]).

This fact leads to the assumption that the non-equilibrium background radiation over an enormous range of energies 10^{-7}-10^{+4} eV is attenuated by a single mechanism. It is obvious that such a mechanism cannot be the reverse Compton effect or the decay of π^0 mesons. We can therefore assume that over the entire range from 10^{-6}-10^4 eV that the background radiation is caused by breaking of electrons in the magnetic field. /22

The question arises regarding the origin of the radiation in the 10^5-10^8 eV region[12]. If we analyze this problem within the framework of the three mechanisms outlined above and rest on the assumption that with $E_\gamma < 10^4$ eV the radiation is produced by a single synchronous mechanism, we must conclude that with $E_\gamma > 10^4$ eV the radiation is produced by this mechanism. In the opposite case, it would be extremely difficult to understand the interruption in the $E_\gamma < 10^4$-10^5 eV region of the radiation spectrum, caused by π^0 decay or the reverse Compton effect.

Hence, we come to an important conclusion: if the background radiation in the 10^{-7}-10^4 eV region is caused by synchronous radiation, then the principle contribution in the 10^5-10^8 eV region is made by this process.

Let us examine the question of the sources of background radiation within the framework of the synchrotron hypothesis.

In contrast to the dual hypotheses (see section II), the principle sources here cannot be the usual galaxies, since experimental data regarding the behavior of the spectral index of the radiation show that in this case it has a gap in the 1000 MHz region [26] as a rule. /23

Apparently, such sources cannot be the weak end medium sized radio galaxies (with a radiated power of less than 10^{26} Watts per $Hz^{-1}ster^{-1}$). The basis for such a conclusion is the calculations which show that in the absence of evolution of sources, the contribution of all radio galaxies to the radio background is less than 15-20% [29-30], we know that there is no basis for

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[12]The 10^4-10^5 eV interval is a transitional region in which the subscript γ_γ changes from the value of $\gamma_\gamma = 1.7$ ($E_\gamma \lesssim 10^4$ eV) to $\gamma_\gamma = 2.2$ ($E_\gamma \gtrsim 10^5$ eV).

assuming the evolution for weak radio galaxies.

Hence, there are powerful radio sources or quasars which can explain the observed radio background, if we assume in accordance with experimental data that they have a strong evolution (see the detailed argumentation on behalf of the necessity for introduction of evolution into the survey by Longeyr [31]).

The experimental basis for the evolution of quasars or an increase in their density in the accompanying system of coordinates are given in a monograph [25] and in the work by Schmidt [32]. Let us examine several consequences of the synchrotron hypothesis. First of all, there is the question about the fate of the strong ultraviolet radiation beyond the Lyman continuum, which arises in conjunction with synchrotron hypothesis in sources.

Direct measurement of this radiation is necessary due to absorption of /24
this radiation in the galaxy.

Therefore, let us carry out some heuristic considerations.

Let us begin by examining the situation as far as quasars are concerned. By way of supplementing the monograph [25] written by Kardashev, Soglasnov and Soglasnova, distributions by radiation frequencies were obtained for 210 quasars; approximately 160 of them lent themselves to determination of spectral indices over a wide energy range (radio and optical). In approximately 50% the intensity in the optical range was higher than the extrapolated curve for the radio range; in 15% it was lower and in 35% the intensity in the optical lies along the extension of a curve which represents the intensity in the radio range.

Let us examine the latter in more detail. If the ultraviolet is absorbed within the limits of the source, then in the final analysis it will be converted into quanta in the optical range.

Within the framework of the synchrotron hypothesis, with a spectral index of $\alpha \sim 0.7$, this would mean that the intensity in the optical range exceeded the corresponding values of the extrapolated curve by 3 to 4 times. It is therefore natural to suggest that in these 35% of the quasars the ultraviolet is practically not absorbed.

The second argument is the direct observation of the line L_β in quasars ZS9 [26, 33]. If the radiation on this line passes through the envelope of the quasar, there is no basis for assuming that the radiation beyond the Lyman continuum[13] cannot also pass through it. /25

On the other hand Shklovskiy [34] noted a long time ago that in view of the fact that the radiation on the hydrogen lines in quasar ZS273 is equal in order of magnitude to the energy of the ultraviolet beyond the Lyman continuum and must therefore must be converted into the optical quanta.

This fact does not contradict our finding that in a large part of the quasars the ultraviolet must go beyond the limits of the envelope without significant absorption.

It is interesting to perform a similar investigation for powerful radio galaxies as well. The most reliable method would be an analysis of the behavior of the spectral indices in the radio and optical ranges. However, we do not have such information. Therefore, we shall limit ourselves to an analysis of this point for the Siefert galaxy MGC4151 and the galaxy M87. Using the data on the density of the intergalactic gas and the temperature of these galaxies (see [35]-[38]), we can obtain a rough estimate of the degree of absorption of hard ultraviolet. We find that it cannot be significant.

If the hard ultraviolet from powerful sources escapes into intergalactic space, it must (according to the findings of current hypothesis) perform /26 ionization of the intergalactic gas [26]. It is necessary to mention in this connection the formation of the spatial zones (similar to the Stremgrem zones) around quasars with a size on the order of several Megaparsecs. In addition, in order to take into account the possible evolution of the density of quasars (according to Schmidt), the total effect of the ultraviolet radiation from all quasars will lead to a high degree of ionization: $Z \approx 2$, $n_H/n \sim 10^{-5}$. This value is even less than that obtained in the dual hypotheses (see section IV),

[13]Note that the optical spectrum of the quasar ZS9 lies outside the extrapolated curve. Hence, this feature is not an unambiguous indication of the complete absorption of the hard ultraviolet.

which has to do with the derivation of Schmidt data by extrapolation to large Z, the error in estimating the average ultraviolet radiation of quasars and failure to take into account the limitation of the radiation of quasars in the radio range in [26].

In conjunction with the possible role of quasars in the formation of background radiation, it is interesting to study the problem of the relationship between the spectrum of the generation of electrons and the spectrum of radiation in compact sources with high radiation density. One gets the impression that it is only in this case, when the extent of the source significantly exceeds the average path of the electrons responsible for radiation, that the stepwise nature of the radiation can be preserved. However, this problem requires additional investigation.

VI. Joint Evaluation of the Dual and Synchrotron Hypotheses /27

In this section we shall evaluate and compare the possible arguments in favor of the hypotheses discussed above as well as those against them.

Let us deal first with the dual hypothesis.

This hypothesis is a good explanation of the experimental data, but it requires additional assumption of the powerful evolution of electron sources.

The most difficult aspect of this hypothesis is the need to allow a discontinuity in the electron spectrum in the sources. Such a discontinuity cannot be explained within the framework of current concepts regarding the acceleration of cosmic particles.

There is however, one experimental fact which agrees with the assumption that the electron spectrum in the sources undergoes a discontinuity. We have in mind the data on the behavior of the spectral index of ordinary galaxies [28]. This discontinuity cannot be simply treated (as is usually done in regard to our galaxy) as a manifestation of processes that brake electrons along the path from the sources to the observer. The fact is that the electrons with low energies (prior to fission), emerging from the galaxies, must produce X-radiation in the process of the Compton effect in connection with the relict radiation. In order for the imposition of this radiation not to exceed

the initial synchrotron spectrum (in this case the spectrum is not expressed by a single law over a wide energy interval), we must have the following condition: /28

$$\varepsilon^{(12)} \ll \varepsilon^{(p)}, \tag{16}$$

where $E^{(12)}$ is the energy density of the galactic electrons, averaged over the Metagalaxy, attenuating the X-radiation due to the reverse Compton effect; $E^{(p)}$ is the energy density of the electrons in radio galaxies (quasars), producing X-radiation by the synchrotron mechanism.

Since the spectral index of the radio background $\alpha = 0.7$, the differential energy spectra of the electrons in the galaxies are expressed by the step function $A_{g,r} E_e^{-2.4} dE_e$ (subscripts g and r refer to the galaxies and the radio galaxies, respectively). Then

$$\varepsilon^{(12)} \sim \frac{A_g}{0.4} E_{e_g}^{-0.4} \tag{17}$$

and

$$\varepsilon^{(p)} \sim \frac{A_r}{0.4} E_{e,r}^{-0.4}, \tag{18}$$

where the boundary energies $E_{eg,r}$ are determined by their characteristic constants of the synchronous and Compton processes: /29

$$E_{eg} \sim \sqrt{\frac{E_\gamma}{E_{R0}}}\, mc^2 \tag{19}$$

(reverse Compton effect),

$$E_{er} \sim \left(\frac{2\nu \cdot 10^5}{H}\right)^{1/2} \qquad (20)$$

(synchrotron radiation, V in Hz, H in Oe, E_e in eV). Then condition (16) is written in the following form:

$$\frac{A_r}{A_g} \gg \left(\frac{E_{er}}{E_{eg}}\right)^{0.4}. \qquad (21)$$

With $\nu \sim 10^{18}$ Hz, $E_{er} \sim (2 \cdot 10^{23}/H)^{1/2}$.

Thus, if $H \sim 10^{-4}$ Oe, (conventional radio galaxies) then (21) leads to the condition:

$$\frac{A_r}{A_g} \gg 10^2, \qquad (22)$$

which is improbable, since the contribution of radio galaxies to the radio background cannot be so much in access of the contribution to conventional galaxies [29]. Hence, in order to get rid of this contradiction, we must again conclude that either the electron spectrum in normal galaxies undergoes a discontinuity or within the framework of the synchrotron mechanism, that the principle contribution is made by sources of quasar type, with a magnetic field apparently reach values of about 1-10 Oe (see [21]). In this case, /30 condition (16) is much weaker:

$$\frac{A_r}{A_g} \gg 1. \qquad (22a)$$

For all of the different questions that have been considered, the validity of the concept regarding the principle sources of the radio background is of primary importance. Unfortunately, there is no definite information in this respect. Sholomitskiy [29] suggests that the principle contribution (sufficient

to explain all of the radio background) is made by normal galaxies; such a viewpoint is a strong support for the dual hypothesis. It is proposed in [30, 31] that radio galaxies (specially if they are subject to strong evolution) may make a critical contribution to the radio backgroud. This finding is in agreement with the synchrotron hypothesis. The next test for the choice between the two hypotheses is a comparison of the spectra in the radio and X-ray regions in the sources. It is scarcely possible to hope that in the near future we will be able to observe ordinary galaxies in the X-ray regions at $Z \gtrsim 2$, which will be necessary to test the dual hypothesis.

Now there are three reliable and identical extragalactic X-ray sources. Data on the intensity of their radiation are given in Table 1, based on the survey in [39].

TABLE 2

/31

Source	Radiated power, erg·sec^{-1}	
	Radio range $10^7 < \nu < 10^{10}$ Hz	$E_\gamma > 1{,}5$ keV
Virgo A (M 87)	$3 \cdot 10^{41}$	10^{43}
Cygnus A (ZS405)	$4 \cdot 10^{44}$	$< 10^{44}$
Quasar (ZS273)	$3 \cdot 10^{43}$	$< 10^{46}$

It follows from Table 1 that the ratio of the powers of the radiation in the X-ray and radio region for sources M 87 and ZS273 is on the order of 100, which is in good agreement with the synchrotron hypothesis[14], while there is no such agreement in the case of source ZS405.

[14]The idea that the radiation from the source M 87 over a wide energy range is explained by synchrotron radiation belongs to Shklovskiy [40].

The synchrotron hypothesis will apparently survive a comparison with the behavior of spectral indices and quasars (although this question requires more careful investigation). An significant number of these sources do not show a noticeable change in the spectral index over comparatively wide energy ranges (see section V).

The role of radio galaxies in the formation of background radiation is less clear. A complete survey of data on the behavior of spectral indices for ~ 60 quasars and ~ 240 radio galaxies, compiled by Kuril'chik [41], leads to the following conclusions. Out of 190 radio galaxies, whose spectra have a relatively simple shape, approximately 55% of this spectra have a discontinuity (with an increase in α) in the radio region ($\nu \sim 1000$ MHz). Therefore, we can conclude that the average radio galaxy makes a relatively small contribution within the framework of the synchronous hypothesis. /32

A study of the dependence of the behavior of spectral indices upon the radiated power is of particular importance in this regard. We do not have any detailed data. Therefore, we have compared the behavior of spectral indices in quasars and radio galaxies on the basis of Kuril'chik's data for purposes of estimation, assuming that the average power of quasars is higher than the power of radio galaxies.

It was found that in the case of quasars the percentage of objects with an increasing spectral index was ~ 30%, i.e., approximately half as many as for radio galaxies. This is in qualitative agreement with the synchrotron hypothesis.

In the most difficult aspect of the synchrotron hypothesis is the existence of a discontinuity in the spectrum of X-radiation in the 10-100 keV region.

The assumption that the electron spectrum in sources is described all the way up to $E \to \infty$ by a single stepped curve is difficult to reconcile with this result[15]. /33

[15]As a rule, the energy spectrum of isotropic X-radiation is measured by means of a single instrument over a short energy range. For a detailed study of the discontinuity, it is necessary to measure the spectrum over a large energy interval (100 times or more larger).

In fact, we can attempt to explain this discontinuity from three positions.

a) The density of the gas in the source of radiation is great enough that a portion of the energy of the electrons is extended in breaking radiation. In this case, however, there will be a significant excess of γ-quanta in the region $E_\gamma \gtrsim$ 10-100 MeV which is obviously not the case.

b) If the effect of distances at which radiation develops corresponds to large Z ($Z \gtrsim 4$-5), the quanta in the region $\gtrsim$ 50-100 keV will undergo absorption due to the Compton effect in the intergalactic gas, if the density of the latter is $\gtrsim \rho_c$ (this idea was expressed by the Rees [42])[16]. A similar effect may be expected for quanta formed in quasars.

However, due to the fact that the cross section of the Compton effect falls with the energy $\sim e_n E_\gamma / E_\gamma$ (with $E_\gamma \gg mc^2$), this effect will be negli- /34
ably small for $E_\gamma \gg mc^2$, and, consequently, it must be expressed at energies of $E_\gamma \sim$ 100 MeV, where the observations agree with the stepped curve over the entire range $\gtrsim$ 100 keV.

The situation is not saved by the fact that with $E_\gamma > 2mc^2$ a new process develops in which the photons are absorbed (forming vapor), since the asymptotic cross section of this process for hydrogen is more than an order of magnitude less than the Thompson cross section[17].

c) The low-energy electrons are emitted by sources without expending all their energy on synchrotron radiation. However, a portion of the energy which is not consumed in the synchrotron radiation changes to X-rays, due to

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[16]A similar effect may be expected for quanta formed in quasars.

[17]One possibility (but one which is not very likely) in regard to point a) and b) is the fact that the spectra of the background photons with high energies has been poorly investigated. The values for the intensity of the photons in the region $E_\gamma \gtrsim$ 50-100 MeV is essentially the upper limits. There are no data at all in the region $E_\gamma \sim$ 5-50 MeV (see Figure 1).

The importance of studying this spectral region was pointed out long ago in connection with other problems [43, 44].

the reverse Compton effect with relict radiation (see [15]). Therefore, an excess X-ray background develops which contradicts observations.

Conclusions

a) The dual and synchrotron hypotheses provide a good description of the experimental data regarding background radiations over a wide energy range.

b) The dual hypothesis requires assumptions regarding the powerful evolution of electrons sources and a discontinuity in the electron generation spectrum. /35

c) The principle source of radiations in this hypothesis consists of the normal galaxies at $Z \gtrsim 2$.

d) It is difficult within the framework of this hypothesis to explain the discontinuity in the electron generation spectrum.

e) In the synchrotron hypothesis, the principle sources are powerful radio galaxies and quasars, subject to powerful evolution.

f) Both hypotheses predict an intense ultraviolet radiation in the Universe.

g) This ultraviolet radiation causes very intense ionization of the intergalactic gas.

h) Therefore, the experimental data on the absence of significant concentration of neutral hydrogen in the Metagalaxy do not contradict the existence of Metagalactic gas with a density close to the critical level.

i) At the present time, there are no data which indicate a high temperature for the intergalactic gas (see appendix 2).

j) There is one important point which both hypotheses have in common. The principle sources of background radiation must arise at considerable ($Z \gtrsim 2$) distances. We can therefore not exclude the possibility that the difference between them has a terminological character (are quasars one of the early stages of evolution of galaxies?). The relationship between the effective magnetic field and the equivalent intensity of the relict radiation is more significant.

In the dual hypothesis $H_{eff} \ll 10^{-5}$ Oe; however, for the synchrotron hypothesis we must have $H_{eff} \gg 10^{-5}$ Oe.

APPENDIX

1. Influence of the Red Shift on the Spectrum of Ultraviolet Radiation

We shall deal here with the possible change in the spectrum in the ultraviolet range caused by the red shift. If the limiting energy $E_{eL} \lesssim 100$ MeV, then for radiation in the region of the Lyman continuum the electrons would have to be braked to an energy of ~ 50 MeV. It follows from (2) that electrons with such energy will effectively radiate the ultraviolet $Z > Z^* \sim \sim 0.3$. Therefore, formula (6) gives a somewhat more elevated value for the intensity of the ultraviolet. The coefficient of attenuation produced by the red shift has an approximate form:

$$\alpha \approx \frac{(\omega^*)^{4.5-\beta} - \omega_i^{4.5-\beta}}{1 - \omega_i^{4.5-\beta}}. \qquad (1\ D)$$

If $\beta \ll 4.5$, $\alpha \sim 1/3$; if $\beta > 4$, $\alpha \sim 1$.

2. The Influence of the Ultraviolet on the Heat Regime of the Metagalactic Gas

The significant liberation of heat caused by the ultraviolet is possible only for an interval of time t_H, characteristic for the ionization of intergalactic gas. The $t_H \sim 1/I\sigma \sim 10^{14}$ sec (I is the total ultraviolet flux). Let us examine the influence of the ultraviolet during time t_H.

In order for role to be significant, it is necessary to satisfy the inequality:

$$L_+ - L_- \geq L_{exp}, \qquad (2\ D)$$

where L_+ is the influx of energy produced by the ultraviolet in a unit volume; L is the loss of energy and L_{exp} is the loss of energy due to expansion of the Universe.

The principle process governing the loss of energy in the interval of temperatures of interest to us $T \sim (10^4\text{-}10^5)°K$ is the radiation from helium-

-hydrogen plasma. Let us write in order of significance the numerical values of the terms[18], which enter into an inequality (2 D):

$$L_{+} \sim 10^{-36} \omega^{-(3+\beta)} \text{ erg/cm}^3\text{/sec} \qquad (3\text{ D})$$

Assuming that the entire ultraviolet energy is converted to heat.

$$L_{-} \sim 10^{-33} \left(\frac{\rho}{\rho_c}\right)^2 \omega^{-6} \text{ erg/cm}^3\text{/sec}, \qquad (4\text{ D})$$ /38

$$L_{exp} \sim 10^{-32} \frac{\rho}{\rho_c} \omega^{-4} \sqrt{1+\frac{\rho}{\rho_c} z} \text{ erg/cm}^3\text{/sec} \qquad (5\text{ D})$$

It follows from (3 D)-(5 D) that with $\rho/\rho_c \sim 1$, the ultraviolet radiation may have its effect during time t_H only at values of $\beta > 7$-8 and $w < 1/5$.

[18]For exact values, see [21].

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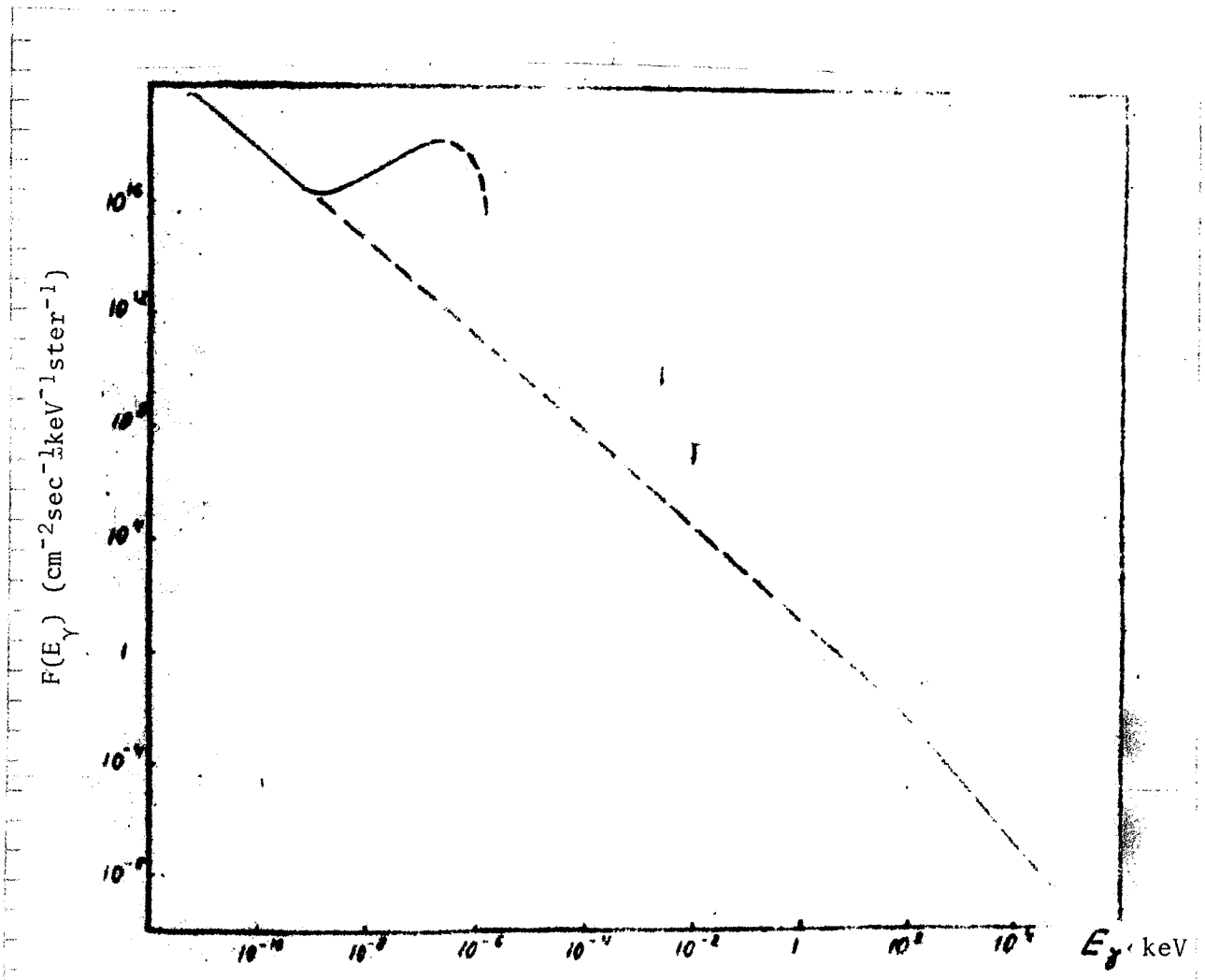
$F(E_\gamma)$ (cm^{-2}sec^{-1}keV^{-1}ster^{-1})
E_γ, keV